Semi-Annual Report
July - December 1992

Michael D. King
Goddard Space Flight Center
Greenbelt, MD 20771

I. Task Objectives

The Moderate Resolution Imaging Spectroradiometer (MODIS) being developed for the Earth Observing System (EOS) is well suited to the global monitoring of atmospheric properties from space. Among the atmospheric properties to be examined using MODIS observations, clouds are especially important, since they are a strong modulator of the shortwave and longwave components of the earth's radiation budget. A knowledge of cloud properties (such as optical thickness and effective radius) and their variation in space and time, which are our task objectives, is also crucial to studies of global climate change. In addition, with the use of related airborne instrumentation, such as the Cloud Absorption Radiometer (CAR) and MODIS Airborne Simulator (MAS) in intensive field experiments (both national and international campaigns, see below), various types of surface and cloud properties can be derived from the measured bidirectional reflectances. These missions have provided valuable experimental data to determine the capability of narrow bandpass channels in examining the Earth's atmosphere and to aid in defining algorithms and build an understanding of the ability of MODIS to remotely sense atmospheric conditions for assessing global change. Therefore, the primary task objective is to extend and expand our algorithm for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from MODIS. The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a. MODIS-related Instrumental Research

After careful consideration of changing the saturation temperature of the MODIS fire channel (channel 21 at 3.75 µm), Michael King and Yoram Kaufman both agreed to replace the 3.75 µm fire channel with one at 3.96 µm that saturates at 500 K. Also, we supported the replacement of the 4.565 µm channel with one at 1.375 µm, as recommended by Bo-Cai Gao and Yoram Kaufman. This suggestion, which should enhance the retrieval of cirrus clouds, was accepted by the Science Team. The Atmospheres Group also recommended channel locations on the SWIR / MWIR and LWIR focal planes to optimize science by minimizing misregistration errors. Finally, the Atmospheres Group recommended a 4 strip "segmented" detector which would increase the Modulation Transfer Function (MTF) for many of the SWIR/MWIR channels which currently are unable to be produced with a high enough yield due to the "large" size of the detector element (540 µm).

The final MAS calibration coefficients for the FIRE Cirrus Experiment, based out of Houston during November and December 1991, were completed by Tom Arnold. The MAS visible and near-IR calibration data for the ASTEX (Atlantic Stratocumulus Transition Experiment), based in the Azores during June 1992, were also studied. Cold chamber data from both pre- and post-ASTEX test flights showed that the calibration coefficients changed somewhat with temperature in channels at 1.62 and 2.14 µm. Analysis of ground calibrations performed during ASTEX and cold chamber data obtained at Ames Research Center showed good consistency. However, comparisons with the NASA Ames 30-inch integrating sphere showed good agreement only in channels at 0.67, 1.62, and 2.14 µm, but poor agreement at 0.88 and 0.95 µm. More work is needed to resolve this discrepancy.

Channel configurations for MAS in the upcoming TOGA/COARE (Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment, based in Townsville, Australia during January and February 1993) and subsequent CEPEX (Central-Equatorial Pacific Experiment, based in Nadi, Fiji during March 1993) deployments has been selected to be 0.665, 0.875, 1.623, 1.83, 2.142, 3.725, 8.563, 11.002, 12.032, 13.186 and 13.952 µm, as agreed by Michael King and Paul Menzel.

Calibrations of CAR using both integrating sphere and hemisphere sources, conducted prior to LEADEX (Lead Experiment, conducted in the Beaufort Sea, Alaska during April 1992) have been carefully re-analyzed and shown to be in good agreement for both sources. Preliminary results from post-flight calibrations of CAR, conducted after the LEADEX and the ASTEX field experiments, showed meaningful data for channels 1 to 7 (0.50-1.25 µm) and no data for channels 8 to 13 (filter wheel channels between 1.55 and 2.29 µm). The signal from the filter wheel channels was very noisy during both LEADEX and ASTEX experiments as well as during in-field calibration at Lajes when the InSb detector was not cooled by the liquid nitrogen properly. Correction to the measurements of LEADEX and ASTEX will be done solely based on calibrations of channels 1 to 7, and the pre-flight calibrations of channels 8-13.

Responding to this problem, as well as other requirements, CAR is currently undergoing a major upgrade. Michael King has decided to replace the old high pressure nitrogen Joule-Thomson InSb detector and cooling system of the filter wheel channels with a new Stirling-cycle cryogenic cooler and InSb detector assembly, both to improve their sensitivity and reliability and to reduce the requirement to have a source of high pressure nitrogen gas available at remote field experiment locations. Following this upgrade, the CAR will be operating in two different configurations: an ultraviolet and a cloud absorption mode. The main difference is that the usual non-absorbing channel (0.754 µm) in the cloud absorption mode will be replaced by a new uv-B channel (0.30 µm) in the ultraviolet mode. This will, hopefully, enable us to measure the radiation available for photochemical reactions and new particle production in the upper layers of clouds.

b. MODIS-related Algorithm Study

After successfully porting and running our cloud retrieval codes from the IBM 3081 to the Cray YMP, Si-Chee Tsay has expended much effort on case studies, obtained from the MAS ASTEX data (subsequently applicable to MODIS data). An interesting case (for cloud microphysics and radiation interaction) occurred on June 17 during ASTEX (Flight line 14), and was therefore processed to determine the cloud optical thickness, effective particle radius and their statistical properties (see section IIIb for details). To make our retrieval algorithm complete, the Rayleigh scattering, aerosol scattering and cloud geometry effects need be considered, and have thus far not been taken into account. Some efforts have been spent to study the bidirectional reflectance introduced by a clear atmosphere having a simple Rayleigh phase function, ozone absorption (at red light) and a Lambertian surface with varying albedos. The simulated angular distribution of reflected radiance shows dependency on the viewing geometry. A more complex scattering phase function for aerosol and cloud particles will be used to simulate cloud top directional reflectance and to gain a better understanding of these atmospheric corrections.

Since the recommendation to include a 1.38 µm channel (for cirrus cloud detection) on MODIS, the effects of cloud geometry (a distribution of cloud properties vs. plane-parallel ones) on reflected radiance have been studied to some degree to begin to assess whether cloud microphysics uncertainties or cloud spatial inhomogeneities dominate the reflected signal. The vertical heating rate distribution for high cirrus clouds at 1.64 µm channel have also been simulated. These studies will provide some information on the atmospheric correction to the retrieval algorithm.

Si-Chee Tsay has continued to work on radiation and microphysics models to simulate the scattered radiation field observed from the Kuwait Oil Fire smoke obtained from the CAR. The microphysics data of these smokes were determined from a combination of two in situ aerosol instruments, each having different dynamical ranges, to compute the optical properties of the smokes. The results of the simulated radiance field will be compared with CAR measurements. Forward simulations of the multiple scattered radiation field at 0.63 and 0.82 µm were first conducted for water and ice clouds at different values of the effective radius to investigate the accuracy and efficiency of the model.

On the surface property studies, much effort has been devoted to processing and understanding the bidirectional reflection pattern of multi-year ice and snow surface, obtained from the CAR during LEADEX. Some discussions are provided in section III.

c. MODIS-related Services

Meetings:

1. attended the July IWG meeting in Keystone, Colorado, where considerable discussion focused on further descoping of the EOS mission (blue and red team recommendations).

2. worked on responding to suggested instrument and data product descopes suggested for MODIS as part of the Administrator-directed red and blue team evaluation of ways to reduce the EOS Project runout budget by 30% through FY2000.

3. chaired the MODIS Technical Team meetings twice during the month of August and began working with Jeff Dozier and the EOS Project Science Office on aspects of being appointed to succeed Dr. Dozier as the EOS Senior Project Scientist.

4. attended the MODIS Preliminary Design Review in Santa Barbara on October 21-23, the MODIS Calibration Group meeting on October 26, and chaired the Atmospheres Discipline Group at the MODIS Science Team meeting on October 27-29. These meetings proved very valuable in gaining further insight into the fine details of the MODIS instrument as well as its complex calibration capabilities and data structures.

Seminars:

1. in August, gave a presentation on MODIS at the ASPRS Annual Convention in Washington, DC.

2. in September, was invited to give a seminar at the Center for Climate System Research (CCSR) at the University of Tokyo on the “Radiative and Microphysical Properties of Clouds Modified by Pollution from Ships,” as well as give an invited paper at the International WCRP Symposium, entitled “Radiative and microphysical properties of marine stratocumulus clouds.” The WCRP Symposium consisted of 8 sessions over a six day period, and included sessions on TOGA, Cloud-radiation processes, Cloud distribution, and the Microstructure and radiative properties of both water and ice clouds. This was the first scientific meeting in which MAS-analyzed optical thickness and particle radius retrievals were presented. There was much interest in this invited paper, MAS retrievals, ship tracks and their influence on climate, and the EOS Program in general.

3. in November, attended the FIRE meeting at Fairfax, VA and presented some results obtained during the ASTEX and Cirrus Intensive Field Observations (IFOs).

III. Data/Analysis/Interpretation

a. Data Processing

Michael King and Si-Chee Tsay have documented the mission flight logs (ER-2 and C-131A, respectively) for the ASTEX and LEADEX and prioritized the research flights for data analysis. The mission flight logs of ER-2 FIRE Cirrus IFO (Nov. - Dec. 1991) have also been documented by Michael King. Tom Arnold and Ward Meyer have processed the navigation (ground track) and microphysical data from C-131A flights for both LEADEX and ASTEX data. Also, the production of all ER-2 FIRE Cirrus IFO ground tracks has been completed. All ground tracks flown by the University of Washington C-131A during ASTEX have been completed. Ground tracks are presently being produced for all ER-2 flights during ASTEX on the same map projection and scale as the C-131A flight tracks flown concurrently. This permits a quick determination and selection of the co-located data for in situ microphysics for validating the MAS retrievals of cloud optical thickness and effective radius of the cloud droplets.

Based on the final calibration data, Liam Gumley has completed the processing of all MAS level-1B data for the FIRE Cirrus data set. All flight lines from October 31, 1991 to December 7, 1991 have been calibrated, geolocated, stored as netCDF files (network Common Data Format), and written to Exabyte 8500 tape. A total of 154 flight lines were processed, containing 638651 scanlines. The volume of netCDF output data produced was approximately 12.27 Gigabytes. Table 1 summarizes the processed data for the FIRE Cirrus IFOs. In addition, the MAS quicklook images for these flights are available (one visible and one infrared channel). The images are sampled every 4th line and every 4th pixel. Currently Tom Arnold is working on producing a catalog of quicklook images for the FIRE Cirrus IFOs. This process involves downloading (from LTP2) two GIF image files for each flight line of each ER-2 flight, running through a GIF converter and then copying to a MacDraw Pro file. Thus far images for 12, 14, and 18 November have been produced.

For the CAR data sets, Ward Meyer has modified CARANLYS and CARASPLT codes to be compatible with the new (seven level) manual gain structure and reorganized the input files to reflect the changes of the filter wavelengths. Active scan tape files for the LEADEX flights were produced through program CARASCAN and are ready for scientific analysis such as the surface (snow and sea ice, see below) and cloud top bidirectional reflectance. Da-Sheng Feng has completed porting the CARANLYS code from the IBM Gibbs computer to the Cray YMP. A test case which determines the spectral absorption of solar radiation by clouds was run and it worked quite well. He is continuing to work on examining and analyzing all the CAR data in the diffusion domain obtained during the 1987 FIRE experiments.

b. Analysis and Interpretation

Si-Chee Tsay has completed the setup of running the netCDF formatted data on the Cray-YMP for the first time. An interesting case (cloud microphysics and radiation interaction) on June 17 (flight line 14) during ASTEX has been selected and run to retrieve the effective radius and optical thickness of these clouds. For example, Figure 1 shows the reflection function for 0.665 and 2.142 µm (channels 2 and 6 of MAS) and Figure 2 shows brightness temperature for 8.563 and 11.002 µm (channels 8 and 9). The first two channels have been used in our retrieval scheme to infer the cloud properties and the last two channels (including channel 10 at 12.032 µm) are used by Paul Menzel's group in retrieving cirrus and surface properties. The ER-2 was flying from the top (South) to the bottom (North) and the MAS was scanning from left to right in the figure (clockwise with respect to flight direction). The nadir pixel resolution is about 45 meters, assuming an average 18 kilometers altitude of ER-2. The synoptic condition of this day was: cloud top height about 1000 meters and a transition of clean maritime air (one-third from the top) to highly polluted continental air from Europe.

Figure 3 shows the retrieved cloud properties of optical thickness (Fig. 3a) and effective radius (Fig. 3b). Color images of these results were created using Spyglass TRANSFORM by Tom Arnold. The spatial distribution of these clouds for different types of air masses are clearly displayed in distinct patterns. However, some outstanding questions immediately arise. First, the trend of optical thickness is generally increased from the right-hand-side pixels toward the left (or NNE to SSW direction). Is this related to the north-east flow of anticyclone that transports the aerosols as CCN from Europe or to the sun-sensor viewing angle that aerosols aloft enhance the forward reflection at the right-hand-side pixels? We need the capability of correcting Rayleigh and aerosol scattering in the retrieval algorithm. Secondly, in the middle and lower part of the retrieved effective radius there are two bands of anomalously large droplets. (Dark signal in both channels for a plane-parallel cloud geometry is translated to the highly absorbing large drop.) This is a false detection due to the lack of correction in cloud boundary.

To obtain quantitative statistics on these clouds, Figures 4 and 5 show the marginal probability density function of retrieved cloud optical thickness and effective radius, respectively. Figures 4a and 5a were produced by selecting 165 processed scan lines (every 4th) of both continental and maritime clouds in which the cloud boundaries are avoided. Figures 4b and 5b represent the whole scene totaling 435 processed scan lines. The retrieved optical thickness of maritime clouds is singly peaked around 6 but bimodal with peaks at 10 and 14 for the continental clouds. Although the retrieved effective radius for both air masses is bimodal which peaked at 4 and 6 µm, it is speculated that the first peak may be contaminated by the aerosols aloft. The main difference between these two curves is at the tail of the large drop sizes. These two figures together outline the general characteristics of continental and maritime clouds. Figure 6 shows the joint probability density functions of the retrieved optical thickness and effective radius for both air masses. A negative correlation is shown on both cases, with some complication in the continental clouds.

The microphysics data (e.g., liquid water content and effective radius) on June 17 of ASTEX showed significant discrepancies between PVM (a new liquid water content probe from Gerber Scientific Inc.) and FSSP (Forward Scattering Spectrometer Probe from Particle Measuring Systems, Inc.). Results from the PVM were considered more accurate. However, PVM data at the best co-location times (Flight lines 6 and 11) between ER-2 and C-131A were missing, due to the first and the only occasion of water leakage into the PVM. Hermann Gerber found that the difference in effective radius between the two probes is systematic in the whole ASTEX data and has corrected the FSSP data based on the PVM data. This will provide us the opportunity for model verification with the in situ measurements.

Tom Arnold and Ward Meyer have upgraded the CAR utility programs to be flexible in responding to CAR parameter changes, such as filter wavelengths and calibration coefficients, and to be able to process subsections of active scan data. This is very useful in processing the full bi-directional reflection and transmission properties of the surface and the atmosphere, respectively. Figure 7 shows the surface bi-directional reflection functions for the multi-year snow and ice obtained by CAR during the April LEADEX measurements. Data for channels 1, 6, 7, and 9 (0.5, 1.22, 1.27 and 1.64 µm) were chosen to demonstrate the spectral characteristics of snow and ice. The solar zenith angles at the time of measurement were about 65.25 degrees. The striking features in these polar plots are: the blind (specular reflection) and hot (direct backscattering) spots around the principal plane (0 - 180 degree azimuthal plane); the darkest spot around 110 degrees azimuthal plane; nearly isotropic scattering at all viewing angles except near the forward (larger than about 40 degrees nadir) and the backward (larger than 60 degrees nadir) portions. This is clearly demonstrated in Figure 8, which plots the details of reflection functions for the principal plane.

IV. Anticipated Future Actions

a. participate in the TOGA-COARE and CEPEX campaigns, taking place in January and February from Townsville, Australia, and March from Nadi, Fiji, respectively, and the follow-up data analysis;

b. attend the EOS Topical Science Workshop on Atmospheric Corrections in Greenbelt (May 17-18). This workshop should be a useful opportunity to further explore the progress in atmospheric aerosol retrievals using MODIS, MISR, POLDER or EOSP data;

c. attend the AGU Spring Meeting in Baltimore (May 24-28) to present results from the ASTEX and LEADEX missions;

d. continue the efforts to refine the data analysis algorithm and to increase its ability to analyze data obtained from instruments other than MCR and MAS;

e continue to analyze the bidirectional reflectance measurements obtained during the LEADEX and ASTEX experiments;

f. re-examine more carefully the retrieval of cloud optical and microphysical properties by using data gathered from MAS, especially on the atmospheric corrections of Rayleigh and aerosol scattering.

V. Problems/Corrective Actions

No problems that we are aware of at this time.

VI. Publications

1. King, M. D., 1992: Directional and spectral reflectance of the Kuwait oil-fire smoke. *J. Geophys. Res.*, **97**, 14545-14549.

2. Nakajima, T. and M. D. King, 1992: Asymptotic theory for optically thick layers: Application to the discrete ordinates method. *Appl. Opt.*, **31**, 7669-7683.

3. Harshvardhan, and M. D. King, 1993: Comparative accuracy of diffuse radiative properties computed using selected multiple scattering approximations. *J. Atmos. Sci.*, in press.

4. King, M. D., L. F. Radke and P. V. Hobbs, 1993: Optical properties of marine stratocumulus clouds modified by ships. *J. Geophys. Res.*, in press.

6. King, M. D., 1995: Radiative properties of clouds. *Aerosol-Cloud-Climate Interactions*, P. V. Hobbs, Ed., Academic Press, in press.

Table 1. MAS FIRE Data Processing Status. All flight lines from October 31, 1991 to December 7, 1991 have been calibrated, geolocated, stored as netCDF files, and written to Exabyte 8500 tape. The volume of netCDF output data produced was approximately 12.27 GB.

Flight Date	***Region covered***	***Number of flight lines***	***Number of scanlines***
10/31/91	Ames test flight	3	25447
11/12/91	Ferry flight	1	7920
11/14/91	Coffeyville KS	16	8661
11/18/91	Coffeyville KS	14	47985
11/21/91	Coffeyville KS	12	58011
11/22/91	Coffeyville KS	9	40439
11/24/91	Gulf coast TX, LA	12	77140
11/25/91	Coffeyville KS	17	74235
11/26/91	Coffeyville KS	16	64131
12/03/91	Gulf coast TX, LA	14	51812
12/04/91	Gulf coast TX, LA	8	28584
12/05/91	Coffeyville, Gulf	19	77764
12/07/91	Coffeyville KS	12	36041
11/16/91	Ground calibration	1	10481
11/20/91	Ground calibration	1	6077
11/23/91	Ground calibration	1	9849
	Totals	*154*	*638651*

The flight data listed above have been processed to Level-1B with the following features:

- Temperature dependent visible/near-infrared calibration coefficients;
- MAS/INS internal clock offset corrected in MAS data to nearest 0.16

second (= one scan period);

- Quicklook imagery from 0.67 µm and 12.0 µm channels generated in GIF image format;
- Flight summary text generated;
- Flight track maps over CIA world database coastline generated (hardcopy and GIF image format);
- Output data sets created on Exabyte 8500 tape.

Quicklook images and flight summaries are available for anonymous FTP at ltpiris2.gsfc.nasa.gov.